ENGLISH TRANSLATION OF INTERNATIONAL APPLICATION AS FILED

DESCRIPTION

BOUNDARY ACOUSTIC WAVE DEVICE

Technical Field

The present invention relates to a boundary acoustic wave device using a Stoneley wave, and more particularly, relates to a boundary acoustic wave device using a Stoneley wave and having the structure in which electrodes are disposed at a boundary between a piezoelectric substance and a dielectric substance.

Background Art

Heretofore, various surface acoustic wave devices have been used for RF and IF filters in mobile phones, resonators in VCOs, VIF filters in televisions, and the like. Surface acoustic wave devices use a surface acoustic wave, such as a Rayleigh wave or a first leaky wave, which propagates along a surface of a medium.

Since propagating along a surface of a medium, a surface acoustic wave is sensitive to the change in surface condition of the medium. Accordingly, in order to protect a surface of a medium along which a surface acoustic wave propagates, a surface acoustic wave element has been hermetic-sealed in a package in which a cavity portion is provided so as to face the wave-propagating surface. Since the package having a cavity portion as described above has been used, the cost of the surface acoustic wave device is inevitably increased. In addition, since the size of the package becomes much larger than that of the surface acoustic wave element, the size of the surface acoustic

wave device is inevitably increased.

On the other hand, among acoustic waves, in addition to the above surface acoustic waves, a boundary acoustic wave is present which propagates along a boundary between solid substances.

For example, in the following non-patent document 1, a boundary acoustic wave device has been disclosed in which an IDT is formed on a 126° rotated Y plate X-propagation $LiTaO_3$ substrate and a SiO_2 film having a predetermined thickness is formed on the $LiTaO_3$ substrate and the IDT. In this document, it has been disclosed that an SV+P type boundary acoustic wave, which is a so-called Stoneley wave, propagates. In the non-patent document 1, it has been disclosed that when the thickness of the above SiO_2 film is set to 1.0 λ (λ indicates the wavelength of a boundary acoustic wave), an electromechanical coefficient of 2% is obtained.

The boundary acoustic wave propagates in the state in which energy is concentrated on a boundary portion between solid substrates. Hence, since energy is not substantially present on the bottom surface of the above $LiTaO_3$ substrate and the surface of the SiO_2 film, the properties are not changed due to the change in surface conditions of the substrate and the thin film. Accordingly, a package having a cavity portion is not required, and hence the size of the boundary acoustic wave device can be reduced.

In addition, in the following non-patent document 2, a boundary acoustic wave called a Stoneley wave has been disclosed

which propagates in the structure in which a SiO_2 film is formed on a 128° rotated Y plate X-propagation $LiNbO_3$ substrate. According to the analysis of the non-patent document 2, it is shown that when the SiO_2 is in its natural state, since the displacement is not concentrated on the boundary between the SiO_2 layer and the $LiNbO_3$ substrate, a boundary acoustic wave is not generated, and that when the Lame constant indicating the elasticity of SiO_2 is changed from an inherent value of 0.3119×10^{11} N/m^2 to 0.4679×10^{11} N/m^2, the displacement is concentrated on the boundary, so that a boundary acoustic wave is generated. In addition, according to the experimental result of the non-patent document 2, it has also been disclosed that even when conditions for forming the SiO_2 layer are variously changed, a SiO_2 film cannot be formed in which a boundary acoustic wave propagates.

Non-Patent Document 1: "Piezoelectric Acoustic Boundary Waves Propagating Along the Interface Between SiO_2 and $LiTaO_3$" IEEE Trans. Sonics and ultrason., VOL. SU-25, No. 6, 1978 IEEE

Non-Patent Document 2: "Piezoelectric Boundary Acoustic Wave of Layered Substrate" authored by Nakajo, Yamanouchi, and Shibayama, Technical Report of IEICE, US80-4, 1980

Disclosure of Invention

In a boundary acoustic wave device, a large electromechanical coefficient, a small propagation loss, a small power flow angle, and a small temperature coefficient of frequency have been required. The loss caused by the propagation

of a boundary acoustic wave, that is, the propagation loss, may degrade the insertion loss of a boundary acoustic wave filter or may also degrade the resonant resistance or the impedance ratio of a boundary acoustic wave resonator, the impedance ratio being a ratio between the impedance at a resonant frequency and that at an antiresonant frequency. Hence, the propagation loss is preferably decreased as small as possible.

The power flow angle is an angle indicating the difference between the direction of the phase velocity of a boundary acoustic wave and the direction of the group velocity of energy thereof. When the power flow angle is large, it is necessary to obliquely dispose an IDT in conformity with the power flow angle. Hence, electrode designing becomes complicated. In addition, the loss caused by the deviation in angle is liable to be generated.

Furthermore, when an operating frequency of a boundary acoustic wave device is changed by the temperature, practical pass band and stop band are decreased in the case of a boundary acoustic wave filter. In the case of a resonator, when an oscillation circuit is formed, the above change in operating frequency caused by the temperature results in abnormal oscillation. Hence, the change in frequency per degree centigrade, which is TCF, is preferably decreased as small as possible.

For example, when reflectors are disposed along a propagation direction and outside a region in which a transmitting IDT and a receiving IDT are provided, which

transmits and receives a boundary acoustic wave, respectively, a low-loss resonator type filter can be formed. The band width of this resonator type filter depends on the electromechanical coefficient of a boundary acoustic wave. When the electromechanical coefficient k^2 is large, a broadband filter can be obtained, and when the electromechanical coefficient k^2 is small, a narrowband filter is formed. Hence, it is necessary that the electromechanical coefficient k^2 of a boundary acoustic wave used for a boundary acoustic wave device be appropriately determined in accordance with its application. When an RF filter for mobile phones is formed, the electromechanical coefficient k^2 is required to be 5% or more.

However, in the boundary acoustic wave device using a Stoneley wave, which is disclosed in the above non-patent document 1, the electromechanical coefficient k^2 was small, such as 2%.

In addition, in the $SiO_2/LiNbO_3$ structure disclosed in the above non-patent document 2, a $LiNbO_3$ substrate having large piezoelectric properties is used. Hence, it is believed that compared to the boundary acoustic wave device described in the non-patent document 1, a larger electromechanical coefficient k^2 can be obtained; however, it is quite difficult to form a SiO_2 film so that a boundary acoustic wave propagates, and the non-patent document 2 discloses no measurement result of a Stoneley wave after actually forming the SiO_2 film.

In consideration of the current status of the above-

described conventional techniques, an object of the present invention is to provide a boundary acoustic wave device using a Stoneley wave which has a sufficiently large electromechanical coefficient, small propagation loss, small power flow angle, and a small temperature coefficient of frequency, and which can be manufactured by a simple method.

In accordance with a first aspect of the present invention, there is provided a boundary acoustic wave device using a Stoneley wave, which comprises: a piezoelectric substance, a dielectric substance laminated on one surface of the piezoelectric substance, and electrodes provided at a boundary between the piezoelectric substance and the dielectric substance. In the boundary acoustic wave device described above, the thickness of the electrodes is determined so that the acoustic velocity of the Stoneley wave is lower than that of a slow transverse wave propagating through the dielectric substance and that of a slow transverse wave propagating through the piezoelectric substance.

In accordance with a second aspect of the present invention, there is provided a boundary acoustic wave device using a Stoneley wave, which comprises: a piezoelectric substance, a dielectric substance laminated on one surface of the piezoelectric substance, and electrodes provided at a boundary between the piezoelectric substance and the dielectric substance. In the boundary acoustic wave device described above, the duty ratio of strips forming the electrodes is determined so that the

acoustic velocity of the Stoneley wave is lower than that of a slow transverse wave propagating through the dielectric substance and that of a slow transverse wave propagating through the piezoelectric substance.

In accordance with a third aspect of the present invention, there is provided a boundary acoustic wave device using a Stoneley wave, which comprises: a piezoelectric substance primarily composed of $LiNbO_3$, a dielectric substance laminated on one surface of the piezoelectric substance, and electrodes provided at a boundary between the piezoelectric substance and the dielectric substance. In the boundary acoustic wave device described above, Euler angles (ϕ, θ, ψ) of the piezoelectric substance primarily composed of $LiNbO_3$ are in the respective ranges shown in the following Table 1, and a Stoneley wave having an acoustic velocity of 3,757 m/sec or less is used.

[Table 1]

ϕ (°)	θ (°)	ψ (°)
30	90	225
30	270	135
30	270	315
90	90	135
90	90	315
90	270	45
90	270	225
150	90	45
150	90	225
150	270	135
150	270	315
210	90	135
210	90	315
210	270	45
210	270	225
270	90	45
270	90	225
270	270	135
270	270	315
330	90	135
330	90	315
330	270	45
330	270	225

In accordance with one specific case of the boundary acoustic wave device according to the second or the third aspect of the present invention, the thickness of the electrodes is

determined so that the acoustic velocity of the Stoneley wave is lower than that of the slow transverse wave propagating through the dielectric substance and that of the slow transverse wave propagating through the piezoelectric substance.

In accordance with another specific case of the boundary acoustic wave device according to the third aspect of the present Invention, the duty ratio of strips forming the electrodes is determined so that the acoustic velocity of the Stoneley wave is lower than that of a slow transverse wave propagating through the dielectric substance and that of a slow transverse wave propagating through the piezoelectric substance.

In accordance with a fourth aspect of the present invention, there is provided a boundary acoustic wave device using a Stoneley wave, which comprises: a piezoelectric substance primarily composed of $LiNbO_3$, a dielectric substance laminated on one surface of the piezoelectric substance, and electrodes provided at a boundary between the piezoelectric substance and the dielectric substance. In the boundary acoustic wave device described above, when the density of the electrodes, the thickness thereof, and the wavelength of the Stoneley wave are represented by ρ (kg/m^3), H (λ) and λ, respectively, $H>1/[1/(3\times10^7\times\rho^{-2.22}+0.017)-0.4]$ holds.

In accordance with one specific case of the boundary acoustic wave device according to the fourth aspect of the present invention, the density ρ of the electrodes is set to 4,711 kg/m^3 or more.

In accordance with a fifth aspect of the present invention, there is provided a boundary acoustic wave device using a Stoneley wave, which comprises: a piezoelectric substance primarily composed of $LiNbO_3$, a dielectric substance laminated on one surface of the piezoelectric substance, and electrodes provided at a boundary between the piezoelectric substance and the dielectric substance. In the boundary acoustic wave device described above, when the density of the electrodes, the thickness thereof, and the wavelength of the Stoneley wave are represented by ρ (kg/m^3), H (λ), and λ, respectively, $H>0.03\lambda$ and $\rho>2,699\ kg/m^3$ hold.

In the boundary acoustic wave device according to one of the first to the fifth aspects of the present invention, the electrodes are each primarily composed of an electrode layer comprising at least one selected from the group consisting of Ag, Au, Cu, Fe, Mo, Ni, Ta, W, Ti, and Pt.

The boundary acoustic wave device according to the first aspect of the present invention comprises a piezoelectric substance, a dielectric substance laminated on one surface of the piezoelectric substance, and electrodes disposed at a boundary between the piezoelectric substance and the dielectric substance, and in the above boundary acoustic wave device, the thickness of the electrodes is determined so that the acoustic velocity of a Stoneley wave is lower than that of a slow transverse wave propagating through the dielectric substance and that of a slow transverse wave propagating through the piezoelectric substance.

In addition, the boundary acoustic wave device according to the second aspect of the present invention comprises a piezoelectric substance, a dielectric substance laminated on one surface of the piezoelectric substance, and electrodes disposed at a boundary between the piezoelectric substance and the dielectric substance, and in the above boundary acoustic wave device, the duty ratio of strips forming the electrodes is determined so that the acoustic velocity of a Stoneley wave is lower than that of a slow transverse wave propagating through the dielectric substance and that of a slow transverse wave propagating through the piezoelectric substance.

Hence, according to the first or the second aspect of the present invention, since the thickness of the electrodes or the duty ratio of the strips thereof is determined as described above, a boundary acoustic wave device can be provided in which the Stoneley wave propagates through the dielectric substance and the piezoelectric substance.

The boundary acoustic wave device according to the third aspect of the present invention comprises a piezoelectric substance primarily composed of $LiNbO_3$, a dielectric substance laminated on one surface of the piezoelectric substance, and electrodes disposed at a boundary between the piezoelectric substance and the dielectric substance, and in the above boundary acoustic wave device, Euler angles (ϕ, θ, ψ) of the piezoelectric substance are in the respective ranges shown in Table 1, and a Stoneley wave having an acoustic velocity of 3,757 m/sec or less

is used. Accordingly, as apparent from examples to be described later, spurious can be effectively suppressed, and the electromechanical coefficient k^2 of the Stoneley wave can be increased.

In the boundary acoustic wave device according to the second or the third aspect of the present invention, when the thickness of the electrodes or the duty ratio is determined so that the acoustic velocity of the Stoneley wave is lower than that of the slow transverse wave propagating through the dielectric substance and that of the slow transverse wave propagating through the piezoelectric substance, a boundary acoustic wave device can be provided in which the Stoneley wave can reliably propagate along the boundary between the dielectric substance and the piezoelectric substance.

The boundary acoustic wave device according to the fourth aspect of the present invention comprises a piezoelectric substance primarily composed of $LiNbO_3$, a dielectric substance laminated on one surface of the piezoelectric substance, and electrodes provided at a boundary between the piezoelectric substance and the dielectric substance, and when the density of the electrodes, the thickness thereof, and the wavelength of the Stoneley wave are represented by ρ (kg/m^3), H (λ), and λ, respectively, $H>1/[1/(3\times10^7\times\rho^{-2.22}+0.017)-0.4]$ holds; hence, a boundary acoustic wave device can be provided which uses a Stoneley wave having an appropriate electromechanical coefficient k^2. In particular, when the density ρ of the electrodes is 4,711

kg/m^3 or more, the thickness of the electrodes at a propagation loss of 0 can be decreased, and hence the electrodes can be easily formed.

The boundary acoustic wave device according to the fifth aspect of the present invention comprises a piezoelectric substance primarily composed of $LiNbO_3$, a dielectric substance laminated on one surface of the piezoelectric substance, and electrodes provided at a boundary between the piezoelectric substance and the dielectric substance, and when the density of the electrodes, the thickness thereof, and the wavelength of the Stoneley wave are represented by ρ (kg/m^3), H (λ), and λ, respectively, $H>0.03\lambda$ and $\rho>2,699$ kg/m^3 hold; hence, there is provided a boundary acoustic wave device which uses electrodes composed of a material heavier than Al and in which the Stoneley wave propagates.

In the present invention, when the electrodes are each primarily formed of an electrode layer comprising at least one selected from the group consisting of Ag, Au, Cu, Fe, Mo, Ni, Ta, W, Ti, and Pt, in accordance with the present invention, a boundary acoustic wave device using a Stoneley wave can be provided. In addition, when at least one second electrode layer comprising a metal other than that forming the above electrode layer is further provided, by selecting a metal material forming the second electrode layer, the adhesion of the electrode with the dielectric substance or the piezoelectric substance can be increased, or the electric power resistance can be enhanced.

Brief Description of the Drawings

Fig. 1 is a front cross-sectional view showing a boundary acoustic wave device of one embodiment according to the present invention.

Fig. 2 is a schematic plan view showing an IDT and reflectors, which are formed as electrodes, of a boundary acoustic wave device of one embodiment according to the present invention.

Fig. 3 is a graph showing impedance-frequency characteristics of a boundary acoustic wave device A1 shown in Table 1 formed in Example 1.

Fig. 4 is a graph showing impedance-frequency characteristics of a boundary acoustic wave device A2 shown in Table 1 formed in Example 1.

Fig. 5 is a graph showing impedance-frequency characteristics of a boundary acoustic wave device A3 shown in Table 1 formed in Example 1.

Fig. 6 is a graph showing impedance-frequency characteristics of a boundary acoustic wave device A4 shown in Table 1 formed in Example 1.

Fig. 7 is a graph showing impedance-frequency characteristics of a boundary acoustic wave device A5 shown in Table 1 formed in Example 1.

Fig. 8 is a graph showing impedance-frequency characteristics of a boundary acoustic wave device A6 shown in Table 1 formed in Example 1.

Fig. 9 is a graph showing impedance-frequency characteristics of a boundary acoustic wave device A7 shown in Table 1 formed in Example 1.

Fig. 10 is a graph showing the relationship between an Euler angle ϕ and the acoustic velocity V in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 0°, 0°), and a SiO_2 film is then formed thereon.

Fig. 11 is a graph showing the relationship between an Euler angle ϕ and the electromechanical coefficient k^2 in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 0°, 0°), and a SiO_2 film is then formed thereon.

Fig. 12 is a graph showing the relationship between an Euler angle ϕ and the propagation loss α in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 0°, 0°), and a SiO_2 film is then formed thereon.

Fig. 13 is a graph showing the relationship between an Euler angle ϕ and the temperature coefficient of frequency TCF in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 0°, 0°), and a SiO_2 film is then formed thereon.

Fig. 14 is a graph showing the relationship between an Euler angle ϕ and the power flow angle PFA in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 0°, 0°), and a SiO_2 film is then formed thereon.

Fig. 15 is a graph showing the relationship between an Euler angle ϕ and the acoustic velocity V in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 0°, 90°), and a

SiO_2 film is then formed thereon.

Fig. 16 is a graph showing the relationship between an Euler angle ϕ and the electromechanical coefficient k^2 in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 0°, 90°), and a SiO_2 film is then formed thereon.

Fig. 17 is a graph showing the relationship between an Euler angle ϕ and the propagation loss α in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 0°, 90°), and a SiO_2 film is then formed thereon.

Fig. 18 is a graph showing the relationship between an Euler angle ϕ and the temperature coefficient of frequency TCF in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 0°, 90°), and a SiO_2 film is then formed thereon.

Fig. 19 is a graph showing the relationship between an Euler angle ϕ and the power flow angle PFA in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 0°, 90°), and a SiO_2 film is then formed thereon.

Fig. 20 is a graph showing the relationship between an Euler angle ϕ and the acoustic velocity V in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 90°, 0°), and a SiO_2 film is then formed thereon.

Fig. 21 is a graph showing the relationship between an Euler angle ϕ and the electromechanical coefficient k^2 in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 90°, 0°), and a SiO_2 film is then formed thereon.

Fig. 22 is a graph showing the relationship between an Euler

angle ϕ and the propagation loss α in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 90°, 0°), and a SiO_2 film is then formed thereon.

Fig. 23 is a graph showing the relationship between an Euler angle ϕ and the temperature coefficient of frequency TCF in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 90°, 0°), and a SiO_2 film is then formed thereon.

Fig. 24 is a graph showing the relationship between an Euler angle ϕ and the power flow angle PFA in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 90°, 0°), and a SiO_2 film is then formed thereon.

Fig. 25 is a graph showing the relationship between an Euler angle ϕ and the acoustic velocity V in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 90°, 90°), and a SiO_2 film is then formed thereon.

Fig. 26 is a graph showing the relationship between an Euler angle ϕ and the electromechanical coefficient k^2 in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 90°, 90°), and a SiO_2 film is then formed thereon.

Fig. 27 is a graph showing the relationship between an Euler angle ϕ and the propagation loss α in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 90°, 90°), and a SiO_2 film is then formed thereon.

Fig. 28 is a graph showing the relationship between an Euler angle ϕ and the temperature coefficient of frequency TCF in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate

of (ϕ, 90°, 90°), and a SiO_2 film is then formed thereon.

Fig. 29 is a graph showing the relationship between an Euler angle ϕ and the power flow angle PFA in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (ϕ, 90°, 90°), and a SiO_2 film is then formed thereon.

Fig. 30 is a graph showing the relationship between an Euler angle θ and the acoustic velocity V in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, θ, 0°), and a SiO_2 film is then formed thereon.

Fig. 31 is a graph showing the relationship between an Euler angle θ and the electromechanical coefficient k^2 in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, θ, 0°), and a SiO_2 film is then formed thereon.

Fig. 32 is a graph showing the relationship between an Euler angle θ and the propagation loss α in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, θ, 0°), and a SiO_2 film is then formed thereon.

Fig. 33 is a graph showing the relationship between an Euler angle θ and the temperature coefficient of frequency TCF in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, θ, 0°), and a SiO_2 film is then formed thereon.

Fig. 34 is a graph showing the relationship between an Euler angle θ and the power flow angle PFA in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, θ, 0°), and a SiO_2 film is then formed thereon.

Fig. 35 is a graph showing the relationship between an Euler

angle θ and the acoustic velocity V in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, θ, 90°), and a SiO_2 film is then formed thereon.

Fig. 36 is a graph showing the relationship between an Euler angle θ and the electromechanical coefficient k^2 in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, θ, 90°), and a SiO_2 film is then formed thereon.

Fig. 37 is a graph showing the relationship between an Euler angle θ and the propagation loss α in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, θ, 90°), and a SiO_2 film is then formed thereon.

Fig. 38 is a graph showing the relationship between an Euler angle θ and the temperature coefficient of frequency TCF in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, θ, 90°), and a SiO_2 film is then formed thereon.

Fig. 39 is a graph showing the relationship between an Euler angle θ and the power flow angle PFA in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, θ, 90°), and a SiO_2 film is then formed thereon.

Fig. 40 is a graph showing the relationship between an Euler angle θ and the acoustic velocity V in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, θ, 0°), and a SiO_2 film is then formed thereon.

Fig. 41 is a graph showing the relationship between an Euler angle θ and the electromechanical coefficient k^2 in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°,

θ, 0°), and a SiO_2 film is then formed thereon.

Fig. 42 is a graph showing the relationship between an Euler angle θ and the propagation loss α in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, θ, 0°), and a SiO_2 film is then formed thereon.

Fig. 43 is a graph showing the relationship between an Euler angle θ and the temperature coefficient of frequency TCF in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, θ, 0°), and a SiO_2 film is then formed thereon.

Fig. 44 is a graph showing the relationship between an Euler angle θ and the power flow angle PFA in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, θ, 0°), and a SiO_2 film is then formed thereon.

Fig. 45 is a graph showing the relationship between an Euler angle θ and the acoustic velocity V in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, θ, 90°), and a SiO_2 film is then formed thereon.

Fig. 46 is a graph showing the relationship between an Euler angle θ and the electromechanical coefficient k^2 in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, θ, 90°), and a SiO_2 film is then formed thereon.

Fig. 47 is a graph showing the relationship between an Euler angle θ and the propagation loss α in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, θ, 90°), and a SiO_2 film is then formed thereon.

Fig. 48 is a graph showing the relationship between an Euler

angle θ and the temperature coefficient of frequency TCF in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, θ, 90°), and a SiO_2 film is then formed thereon.

Fig. 49 is a graph showing the relationship between an Euler angle θ and the power flow angle PFA in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, θ, 90°), and a SiO_2 film is then formed thereon.

Fig. 50 is a graph showing the relationship between an Euler angle ψ and the acoustic velocity V in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, 0°, ψ), and a SiO_2 film is then formed thereon.

Fig. 51 is a graph showing the relationship between an Euler angle ψ and the electromechanical coefficient k^2 in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, 0°, ψ), and a SiO_2 film is then formed thereon.

Fig. 52 is a graph showing the relationship between an Euler angle ψ and the propagation loss α in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, 0°, ψ), and a SiO_2 film is then formed thereon.

Fig. 53 is a graph showing the relationship between an Euler angle ψ and the temperature coefficient of frequency TCF in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, 0°, ψ), and a SiO_2 film is then formed thereon.

Fig. 54 is a graph showing the relationship between an Euler angle ψ and the power flow angle PFA in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, 0°, ψ),

and a SiO_2 film is then formed thereon.

Fig. 55 is a graph showing the relationship between an Euler angle ψ and the acoustic velocity V in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, 90°, ψ), and a SiO_2 film is then formed thereon.

Fig. 56 is a graph showing the relationship between an Euler angle ψ and the electromechanical coefficient k^2 in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, 90°, ψ), and a SiO_2 film is then formed thereon.

Fig. 57 is a graph showing the relationship between an Euler angle ψ and the propagation loss α in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, 90°, ψ), and a SiO_2 film is then formed thereon.

Fig. 58 is a graph showing the relationship between an Euler angle ψ and the temperature coefficient of frequency TCF in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, 90°, ψ), and a SiO_2 film is then formed thereon.

Fig. 59 is a graph showing the relationship between an Euler angle ψ and the power flow angle PFA in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (0°, 90°, ψ), and a SiO_2 film is then formed thereon.

Fig. 60 is a graph showing the relationship between an Euler angle ψ and the acoustic velocity V in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, 0°, ψ), and a SiO_2 film is then formed thereon.

Fig. 61 is a graph showing the relationship between an Euler

angle ψ and the electromechanical coefficient k^2 in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, 0°, ψ), and a SiO_2 film is then formed thereon.

Fig. 62 is a graph showing the relationship between an Euler angle ψ and the propagation loss α in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, 0°, ψ), and a SiO_2 film is then formed thereon.

Fig. 63 is a graph showing the relationship between an Euler angle ψ and the temperature coefficient of frequency TCF in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, 0°, ψ), and a SiO_2 film is then formed thereon.

Fig. 64 is a graph showing the relationship between an Euler angle ψ and the power flow angle PFA in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, 0°, ψ), and a SiO_2 film is then formed thereon.

Fig. 65 is a graph showing the relationship between an Euler angle ψ and the acoustic velocity V in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, 90°, ψ), and a SiO_2 film is then formed thereon.

Fig. 66 is a graph showing the relationship between an Euler angle ψ and the electromechanical coefficient k^2 in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, 90°, ψ), and a SiO_2 film is then formed thereon.

Fig. 67 is a graph showing the relationship between an Euler angle ψ and the propagation loss α in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, 90°, ψ), and

a SiO_2 film is then formed thereon.

Fig. 68 is a graph showing the relationship between an Euler angle ψ and the temperature coefficient of frequency TCF in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, 90°, ψ), and a SiO_2 film is then formed thereon.

Fig. 69 is a graph showing the relationship between an Euler angle ψ and the power flow angle PFA in the structure in which Au electrodes are formed on a $LiNbO_3$ substrate of (90°, 90°, ψ), and a SiO_2 film is then formed thereon.

Fig. 70 is a graph showing the relationship between the electrode thickness and the acoustic velocity of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ag.

Fig. 71 is a graph showing the relationship between the electrode thickness and the propagation loss α of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ag.

Fig. 72 is a graph showing the relationship between the electrode thickness and the electromechanical coefficient k^2 of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ag.

Fig. 73 is a graph showing the relationship between the electrode thickness and the temperature coefficient of frequency TCF of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ag.

Fig. 74 is a graph showing the relationship between the

electrode thickness and the acoustic velocity of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Al.

Fig. 75 is a graph showing the relationship between the electrode thickness and the propagation loss α of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Al.

Fig. 76 is a graph showing the relationship between the electrode thickness and the electromechanical coefficient k^2 of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Al.

Fig. 77 is a graph showing the relationship between the electrode thickness and the temperature coefficient of frequency TCF of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Al.

Fig. 78 is a graph showing the relationship between the electrode thickness and the acoustic velocity of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Au.

Fig. 79 is a graph showing the relationship between the electrode thickness and the propagation loss α of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Au.

Fig. 80 is a graph showing the relationship between the electrode thickness and the electromechanical coefficient k^2 of a Stoneley wave in a boundary acoustic wave device formed in

Example 3 in which the electrodes are formed from Au.

Fig. 81 is a graph showing the relationship between the electrode thickness and the temperature coefficient of frequency TCF of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Au.

Fig. 82 is a graph showing the relationship between the electrode thickness and the acoustic velocity of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Cr.

Fig. 83 is a graph showing the relationship between the electrode thickness and the propagation loss α of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Cr.

Fig. 84 is a graph showing the relationship between the electrode thickness and the electromechanical coefficient k^2 of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Cr.

Fig. 85 is a graph showing the relationship between the electrode thickness and the temperature coefficient of frequency TCF of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Cr.

Fig. 86 is a graph showing the relationship between the electrode thickness and the acoustic velocity of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Cu.

Fig. 87 is a graph showing the relationship between the

electrode thickness and the propagation loss α of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Cu.

Fig. 88 is a graph showing the relationship between the electrode thickness and the electromechanical coefficient k^2 of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Cu.

Fig. 89 is a graph showing the relationship between the electrode thickness and the temperature coefficient of frequency TCF of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Cu.

Fig. 90 is a graph showing the relationship between the electrode thickness and the acoustic velocity of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Fe.

Fig. 91 is a graph showing the relationship between the electrode thickness and the propagation loss α of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Fe.

Fig. 92 is a graph showing the relationship between the electrode thickness and the electromechanical coefficient k^2 of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Fe.

Fig. 93 is a graph showing the relationship between the electrode thickness and the temperature coefficient of frequency TCF of a Stoneley wave in a boundary acoustic wave device formed

in Example 3 in which the electrodes are formed from Fe.

Fig. 94 is a graph showing the relationship between the electrode thickness and the acoustic velocity of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Mo.

Fig. 95 is a graph showing the relationship between the electrode thickness and the propagation loss α of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Mo.

Fig. 96 is a graph showing the relationship between the electrode thickness and the electromechanical coefficient k^2 of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Mo.

Fig. 97 is a graph showing the relationship between the electrode thickness and the temperature coefficient of frequency TCF of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Mo.

Fig. 98 is a graph showing the relationship between the electrode thickness and the acoustic velocity of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ni.

Fig. 99 is a graph showing the relationship between the electrode thickness and the propagation loss α of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ni.

Fig. 100 is a graph showing the relationship between the

electrode thickness and the temperature coefficient of frequency TCF of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ni.

Fig. 101 is a graph showing the relationship between the electrode thickness and the acoustic velocity of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ta.

Fig. 102 is a graph showing the relationship between the electrode thickness and the propagation loss α of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ta.

Fig. 103 is a graph showing the relationship between the electrode thickness and the electromechanical coefficient k^2 of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ta.

Fig. 104 is a graph showing the relationship between the electrode thickness and the temperature coefficient of frequency TCF of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ta.

Fig. 105 is a graph showing the relationship between the electrode thickness and the acoustic velocity of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from W.

Fig. 106 is a graph showing the relationship between the electrode thickness and the propagation loss α of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in

which the electrodes are formed from W.

Fig. 107 is a graph showing the relationship between the electrode thickness and the electromechanical coefficient k^2 of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from W.

Fig. 108 is a graph showing the relationship between the electrode thickness and the temperature coefficient of frequency TCF of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from W.

Fig. 109 is a graph showing the relationship between the electrode thickness and the acoustic velocity of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ti.

Fig. 110 is a graph showing the relationship between the electrode thickness and the propagation loss α of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ti.

Fig. 111 is a graph showing the relationship between the electrode thickness and the electromechanical coefficient k^2 of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ti.

Fig. 112 is a graph showing the relationship between the electrode thickness and the temperature coefficient of frequency TCF of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Ti.

Fig. 113 is a graph showing the relationship between the

electrode thickness and the acoustic velocity of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Pt.

Fig. 114 is a graph showing the relationship between the electrode thickness and the propagation loss α of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Pt.

Fig. 115 is a graph showing the relationship between the electrode thickness and the electromechanical coefficient k^2 of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Pt.

Fig. 116 is a graph showing the relationship between the electrode thickness and the temperature coefficient of frequency TCF of a Stoneley wave in a boundary acoustic wave device formed in Example 3 in which the electrodes are formed from Pt.

Fig. 117 is a graph showing the relationship between the density of electrodes and the thickness thereof at which the propagation loss α of a Stoneley wave is 0, the relationship being obtained when boundary acoustic wave devices are formed by variously changing the density of the electrodes in Example 3.

Fig. 118 is a graph showing the relationship between the acoustic velocity and an Euler angle ϕ in a boundary acoustic wave device formed in Example 4 in which Au electrodes and a SiO_2 film are formed on a $LiNbO_3$ substrate of Euler angles (ϕ, 30°, 0°).

Fig. 119 is a graph showing the relationship between the

temperature coefficient of frequency TCF and an Euler angle ϕ in a boundary acoustic wave device formed in Example 4 in which Au electrodes and a SiO_2 film are formed on a $LiNbO_3$ substrate of Euler angles (ϕ, 30°, 0°).

Fig. 120 is a graph showing the relationship between the electromechanical coefficient k^2 and an Euler angle ϕ in a boundary acoustic wave device formed in Example 4 in which Au electrodes and a SiO_2 film are formed on a $LiNbO_3$ substrate of Euler angles (ϕ, 30°, 0°).

Fig. 121 is a graph showing the relationship between the power flow angle PFA and an Euler angle ϕ in a boundary acoustic wave device formed in Example 4 in which Au electrodes and a SiO_2 film are formed on a $LiNbO_3$ substrate of Euler angles (ϕ, 30°, 0°).

Fig. 122 is a graph showing the relationship between the propagation loss α and an Euler angle ϕ in a boundary acoustic wave device formed in Example 4 in which Au electrodes and a SiO_2 film are formed on a $LiNbO_3$ substrate of Euler angles (ϕ, 30°, 0°).

Fig. 123 is a graph showing the relationship between the acoustic velocity and an Euler angle ψ in a boundary acoustic wave device formed in Example 4 in which Au electrodes and a SiO_2 film are formed on a $LiNbO_3$ substrate of Euler angles (0°, 30°, ψ).

Fig. 124 is a graph showing the relationship between the temperature coefficient of frequency TCF and an Euler angle ψ in

a boundary acoustic wave device formed in Example 4 in which Au electrodes and a SiO_2 film are formed on a $LiNbO_3$ substrate of Euler angles (0°, 30°, ψ).

Fig. 125 is a graph showing the relationship between the electromechanical coefficient k^2 and an Euler angle ψ in a boundary acoustic wave device formed in Example 4 in which Au electrodes and a SiO_2 film are formed on a $LiNbO_3$ substrate of Euler angles (0°, 30°, ψ).

Fig. 126 is a graph showing the relationship between the power flow angle PFA and an Euler angle ψ in a boundary acoustic wave device formed in Example 4 in which Au electrodes and a SiO_2 film are formed on a $LiNbO_3$ substrate of Euler angles (0°, 30°, ψ).

Fig. 127 is a graph showing the relationship between the propagation loss α and an Euler angle ψ in a boundary acoustic wave device formed in Example 4 in which Au electrodes and a SiO_2 film are formed on a $LiNbO_3$ substrate of Euler angles (0°, 30°, ψ).

Reference Numerals

1 · · · · · boundary acoustic wave device

2 · · · · · piezoelectric substance

3 · · · · · dielectric substance

4 · · · · · IDT as electrode

5, 6 · · · · · reflector as electrode

Best Mode for Carrying Out the Invention

Hereinafter, with reference to figures, particular examples

of the present invention will be described so as to facilitate the understanding of the present invention.

In order to enable a boundary acoustic wave to propagate between two solid layers, it is required that energy of the boundary acoustic wave be concentrated between the solid layers.

In general, when a high acoustic velocity region and a low acoustic velocity region are present, a wave is concentrated on the low acoustic velocity region and propagates therein. Accordingly, the inventor of the present invention discovered that the condition in which energy is concentrated between two solid layers can be satisfied when the acoustic velocity of a boundary acoustic wave propagating between the solid layers is decreased by increasing the thickness of electrodes using a metal material, such as Au or Cu, which has a high density and a low acoustic velocity as an electrode material provided between the two solid layers, and as a result, the present invention was made.

Heretofore, it has been known that three types of bulk waves propagating in a solid substance, three types of waves, that is, a longitudinal wave, a fast transverse wave, and a slow transverse wave are present, and that they are called a P wave, an SH wave, and an SV wave, respectively. Whether the SH wave or the SV wave becomes a slow transverse wave is determined by the anisotropic properties of a base material. Among the above three types of bulk waves, a bulk wave having the lowest acoustic velocity is a slow transverse wave. When the solid substance is an isotropic substance such as SiO_2, since only one type of

transverse wave propagates therethrough, this transverse wave is a slow transverse wave.

On the other hand, in a boundary acoustic wave propagating through an anisotropic base material such as a piezoelectric substrate, in most cases, three displacement components of the P wave, SH wave, and SV wave propagate while being coupled with each other, and by the primary component, the type of boundary acoustic wave is determined. For example, the above Stoneley wave is a boundary acoustic wave primarily composed of the P wave and the SV wave, and the SH type boundary acoustic wave is a boundary acoustic wave primarily composed of the SH component. In addition, depending on the conditions, the SH wave component and the P wave or the SV wave component may propagate in some cases without being coupled with each other.

In the boundary acoustic wave, since the above three displacement components propagate while being coupled with each other, for example, in a boundary acoustic wave having an acoustic velocity faster than that of the SH wave, the SH component and the SV component leak, and in a boundary acoustic wave having an acoustic velocity faster than that of the SV wave, the SV component leaks. This leaky-wave component causes the propagation loss of the boundary acoustic wave.

Accordingly, when the acoustic velocity of the Stoneley wave is decreased lower than the acoustic velocities of two slow transverse waves of the above two solid layers, energy of the Stoneley wave can be concentrated around electrodes disposed

between the two solid layers, and a Stoneley wave having a large electromechanical coefficient k^2 can be propagated, so that the conditions can be obtained in which the propagation loss is zero. Since an electrode material having a large density has a slow acoustic velocity, when the acoustic velocity of the Stoneley wave is decreased, an electrode material having a large density is preferably used. The present invention was made based on the understanding as described above.

In addition, when at least one of the solid layers is formed from a piezoelectric substance, and a dielectric substance containing a piezoelectric substance is used as the other solid layer, by the electrodes disposed between the solid layers, the Stoneley wave can be excited. The electrodes may include comb electrodes or interdigital electrodes (interdigital transducer, IDT) as disclosed by Mikio SHIBAYAMA in "Surface Acoustic Wave Technology" pp. 57 to 58, published by The Institute of Electronics, Information and Communication Engineers.

Fig. 1 is a schematic front cross-sectional view of a boundary acoustic wave device of one embodiment according to the present invention, and Fig. 2 is a plan view of an electrode structure of the boundary acoustic wave device. In a boundary acoustic wave device 1, a dielectric substance 3 is laminated on a plate-shaped piezoelectric substance 2. At a boundary between the piezoelectric substance 2 and the dielectric substance 3, an IDT 4 and reflectors 5 and 6 are disposed as electrodes. The reflectors 5 and 6 are disposed at two side of the IDT 4 in the

propagation direction of a surface acoustic wave, and hence in this embodiment, a boundary acoustic wave resonator is formed.

The feature of the boundary acoustic wave device of this embodiment is that the IDT 4 and the reflectors 5 and 6 are formed to have a large thickness so that the acoustic velocity of a Stoneley wave is decreased lower than that of a slow transverse wave propagating through the dielectric substance 3 and that of a slow transverse wave propagating through the piezoelectric substance 2.

In this embodiment, the thickness of the electrode is increased so as to decrease the acoustic velocity of the Stoneley wave lower than that of each of the slow transverse waves propagating through the piezoelectric substance 2 and the dielectric substance 3, and hence the energy of the Stoneley wave is concentrated on the boundary between the piezoelectric substance 2 and the dielectric substance 3. Accordingly, a Stoneley wave having a large electromechanical coefficient k^2 can be propagated with a low propagation loss.

In addition to the increase in thickness of the electrodes so as to enable the Stoneley wave to propagate, in the present invention, when the acoustic velocity of the Stoneley wave is decreased lower than that of each of the slow transverse waves propagating through the piezoelectric substance 2 and the dielectric substance 3 by controlling the duty ratio of strips forming the electrodes as described later, the Stoneley wave can be concentrated on the boundary between the above two substances

and can then be propagated.

Incidentally, the duty ratio of strips is a value represented by L/P where L is the width of the strip and P is a distance from the center of a space between adjacent strips to the center of a next space adjacent to the above space.

The structure shown in Fig. 1 is a simple structure in which the IDT 4 and the reflectors 5 and 6 are disposed as the electrodes between the piezoelectric substance 2 and the dielectric substance 3. By the structure described above, boundary acoustic wave devices using a Stoneley wave can be formed using a great number of materials. For example, in the structure disclosed in the non-patent document 2, which is composed of SiO_2/IDT electrode/128° rotated Y plate X-propagation $LiNbO_3$, the Stoneley wave was not confirmed; however, although the Stoneley wave may not be formed when the electrode thickness is small, the Stoneley wave may be allowed to exist when the electrode thickness is increased. Hereinafter, with reference to particular examples, the present invention will be described in detail.

[Example 1]

A 128° rotated Y plate X-propagation $LiNbO_3$ substrate, that is, having Euler angles (0°, 38°, 0°) was prepared as the piezoelectric substance 2. On this $LiNbO_3$ substrate, as an adhesion layer, a NiCr film was formed by an evaporation method. Next, on this adhesion layer, a Au film was formed by an evaporation method, followed by patterning using a lift-off

method, so that the IDT 4 and the reflectors 5 and 6 were formed. In addition, a SiO_2 film was formed by an RF magnetron sputtering method at a film-forming temperature of 200°C so as to cover the IDT 4 and the reflectors 5 and 6.

The number of electrode finger pairs of the IDT 4 and the number of electrode fingers of each reflector were set to 50.5 and 51, respectively.

In addition, the crossing width of the electrode fingers of the IDT 4 was set to 30 λ. On the other hand, an aperture length A (see Fig. 2) of the reflectors 5 and 6 was set to 30.5 λ. In this example, λ was a placement period of the electrode fingers of the IDT 4 and the reflectors 5 and 6. In addition, the duty ratios of the IDT 4 and the reflectors 5 and 6 were each set to 0.5.

As described above, while the NiCr film, the Au film and the SiO_2 film were variously formed as shown in the following Table 2, one-port boundary acoustic wave devices 1 were formed.

[Table 2]

図番	Au(λ)	SiO_2 (λ)	NiCr (λ)
A1	0.075	4.5	0.005
A2	0.060	3.6	0.004
A3	0.056	3.3	0.004
A4	0.050	3.0	0.003
A5	0.043	2.6	0.003
A6	0.038	2.3	0.003
A7	0.030	1.8	0.002

The impedance-frequency characteristics of each of the boundary acoustic wave devices of A1 to A7 shown in Table 2, which were formed as described above, were measured. The results

are shown in Figs. 3 to 9. The impedance on the vertical axis of Figs. 3 to 9 is the value represented by

[Equation 1]

$$20 \times \log_{10} |Z| \text{ [dB]}$$

In addition, in Figs. 3 to 9, the horizontal axis represents the frequency normalized by a resonant frequency of a response of the Stoneley wave.

As apparent from Figs. 3 to 9, in the boundary acoustic wave devices of A1 to A7 shown in the above Table 2, a ratio Za/Zr between an impedance Za at an antiresonant point and an impedance Zr at a resonant point is in the range of 50 to 60 dB, and it is understood that superior resonant characteristics can be obtained.

On the other hand, when a boundary acoustic wave device was formed in a manner similar to that for the above boundary acoustic wave devices except that Al was only used as the electrode material, response of a high order spurious mode was only confirmed, and no response of the Stoneley wave could be confirmed. This result coincides with the experimental result of the above described non-patent document 2. In this example, in order to confirm the response of the Stoneley wave, a damping material was adhered to a chip surface, and the presence of attenuation was measured for the confirmation.

As apparent from the experimental results, when electrodes primarily composed of Au, which is heavier than Al, are used, and the thickness of the electrodes is set to 0.03 λ or more, the response of the Stoneley wave in the $SiO_2/LiNbO_3$ substrate can be

confirmed, which could not be realized in the past, and it is understood that superior resonant characteristics can be obtained.

In addition, also in the case in which a rotated Y plate X-propagation $LiTaO_3$ substrate or a quartz substrate was used as the piezoelectric substance 2, when the thickness of the Au film was set to 0.03 λ or more, it was confirmed that the Stoneley wave can be propagated. Furthermore, also in the case of another piezoelectric substrate, when the thickness of the Au film was set to 0.03 λ or more, it was confirmed that the Stoneley wave can be propagated as is the case described above.

In Figs. 3 to 9, the resonant frequency of the response of the Stoneley wave is 1.0 which is a normalized value. The response at a lower frequency side than that of the Stoneley wave was a spurious response caused by the SH boundary acoustic wave, and a response at a higher frequency side than that of the Stoneley wave was a response by the high order spurious mode.

The response of the high order spurious mode can be suppressed by a method, for example, described in Japanese Patent Application No. 2003-114592.

[Example 2]

In Example 1, the spurious response was generated by the SH type boundary acoustic wave at a lower frequency side than that of the response by the Stoneley wave. In Example 2, this spurious response was intended to suppress this spurious response.

That is, in order to suppress the spurious response by the SH boundary acoustic wave, the relationships of the Euler angle

of a $LiNbO_3$ substrate with the acoustic velocity V, the electromechanical coefficient k^2, the propagation loss α, the temperature coefficient of frequency TCF, and the power flow angle (PFA) of the Stoneley wave and the SH type boundary acoustic wave were obtained. The calculation was performed based on a method disclosed in "A method for estimating optimal cuts and propagation directions for excitation and propagation directions for excitation of piezoelectric surface waves" (J. J. Campbell and W. R. Jones, IEEE Trans. Sonics and Ultrason., Vol. SU-15 (1968) pp. 209 to 217). In the case of a free boundary, the acoustic velocity and the propagation loss were obtained based on the assumption in which the displacements, the potentials, the normal line components of an electric flux density, and the stresses in the up and down direction at respective boundaries between SiO_2 and Au and between Au and $LiNbO_3$ were continuous, the thickness of SiO_2 and that of $LiNbO_3$ were infinite, and the relative dielectric constant of Au was 1. In addition, in the case of a short-circuit boundary, the potentials at the respective boundaries between SiO_2 and Au and between Au and $LiNbO_3$ were regarded as zero. In addition, the electromechanical coefficient k^2 was obtained by the following equation [1]. In this equation, Vf indicates the acoustic velocity of the free boundary.

$k^2=2\times|Vf-V|/Vf$ .... [1]

The temperature coefficient of frequency TCF was obtained from phase velocities V at 20°C, 25°C, and 30°C using the

following equation [2].

$TCF=V^{-1}(25°C)\times[(V(30°C)-V(20°C)/10°C)]-dS$ .... [2]

In the above equation, dS indicates the coefficient of linear thermal expansion of the $LiNbO_3$ substrate in the propagation direction of the boundary acoustic wave.

In addition, the power flow angle PFA at optional Euler angles (ϕ, θ, ψ) was obtained from phase velocities V at angles of ψ-0.5°, ψ, and ψ+0.5° using the following equation [3].

$PFA=\tan^{-1}[V^{-1}(\psi)\times(V(\psi+0.5°)-V(\psi-0.5°)]$ .... [3]

The structure used in this example was a structure in which Au electrodes were formed on a $LiNbO_3$ substrate and a SiO_2 film was then formed thereon. The thickness of the Au electrodes was set to 0.07 λ, the Euler angles were (0°, 0°, ψ), (0°, 90°, ψ), (90°, 0°, ψ), (90°, 90°, ψ), (0°, θ, 0°), (0°, θ, 90°), (90°, θ, 0°), (90°, θ, 90°), (ϕ, 0°, 0°), (ϕ, 0°, 90°), (ϕ, 90°, 0°), and (ϕ, 90°, 90°), and ϕ, θ, ψ were each within 0° to 180°.

The results are shown in Figs. 10 to 69.

In Figs. 10 to 69, a value with a small letter m as a subscript indicates a calculated value at the short-circuit boundary at which the metal film is disposed between the SiO_2 film and the $LiNbO_3$ substrate, and a value with a small letter f as a subscript indicates a calculated value at the free boundary obtained based on the assumption that the relative dielectric constant of the metal film is 1. A value with U2 as a prefix is a calculated value of the SH boundary acoustic wave, and a value with U3 is a calculated value of the Stoneley wave.

When the Stoneley wave is used, the SH boundary acoustic wave causes a spurious response, and ripples are generated in a pass band, or the amount of out-of-band attenuation is degraded. When the electromechanical coefficient k^2 of the SH boundary acoustic wave is 2% or less, the degradation in properties caused by spurious of the SH boundary acoustic wave is reduced, and the boundary acoustic wave device using a Stoneley wave can be used in a relatively wide application. In addition, when the electromechanical coefficient k^2 of the SH boundary acoustic wave is 1% or less, the boundary acoustic wave device using a Stoneley wave can be provided which can be used in a wider application. More preferably, when the electromechanical coefficient k^2 of the SH boundary acoustic wave is 0.1% or less, since the influence of spurious of the SH boundary acoustic wave can be hardly observed, the boundary acoustic wave device using a Stoneley wave according to the present invention can be used for a filter which is required to have a large attenuation amount and for a highly precise resonator in which even a slight resonant spurious response is not allowed.

In Figs. 10 to 69, Euler angles at which the electromechanical coefficient k^2 of the SH boundary acoustic wave is 2% or less are in the ranges of (0°, 0°, 0°) to (0°, 0°, 180°), (0°, 90°, 49°) to (0°, 90°, 131°), (90°, 0°, 0°) to (90°, 0°, 180°), (90°, 90°, 48°) to (0°, 90°, 131°), (0°, -32°, 0°) to (0°, 47°, 0°), (0°, 0°, 90°) to (0°, 180°, 90°), (90°, -39°, 0°) to (90°, 39°, 0°), (90°, 0°, 90°) to (90°, 180°, 90°), (0°, 0°, 0°) to (180°, 0°, 0°),

(0°, 0°, 90°) to (180°, 0°, 90°), and (0°, 90°, 90°) to (180°, 90°, 90°). Euler angles at which the electromechanical coefficient k^2 of the SH boundary acoustic wave is 1% or less are in the ranges of (0°, 0°, 12.5°) to (0°, 0°, 47.5°), (0°, 0°, 62.5°) to (0°, 0°, 107.5°), (0°, 0°, 132.5°) to (0°, 0°, 167.5°), (0°, 90°, 56°) to (0°, 90°, 125°), (90°, 0°, -18°) to (90°, 0°, 18°), (90°, 0°, 42°) to (90°, 0°, 78°), (90°, 0°, 102°) to (90°, 0°, 138°), (90°, 0°, 162°) to (90°, 0°, 180°), (90°, 90°, 57°) to (90°, 90°, 127°), (0°, 13°, 0°) to (0°, 42°, 0°), (0°, 0°, 90°) to (0°, 180°, 90°), (90°, -32°, 0°) to (90°, 32°, 0°), (90°, 70°, 90°) to (90°, 110°, 90°), (12°, 0°, 0°) to (48°, 0°, 0°), (72°, 0°, 0°) to (107°, 0°, 0°), (132°, 0°, 0°) to (167°, 0°, 0°), (-18°, 0°, 90°) to (18°, 0°, 90°), (42°, 0°, 90°) to (78°, 0°, 90°), (102°, 0°, 90°) to (138°, 0°, 90°), and (0°, 90°, 90°) to (180°, 90°, 90°). Euler angles at which the electromechanical coefficient k^2 of the SH boundary acoustic wave is 0.1% or less are in the ranges of (0°, 0°, 26°) to (0°, 0°, 36°), (0°, 0°, 86°) to (0°, 0°, 96°), (0°, 0°, 146°) to (0°, 0°, 156°), (0°, 90°, 80°) to (0°, 90°, 111°), (90°, 90°, 110°) to (90°, 00°, 119°), (0°, 26°, 0°) to (0°, 34°, 0°), (0°, 0°, 90°) to (0°, 180°, 90°), (90°, -14°, 0°) to (90°, 14°, 0°), (26°, 0°, 0°) to (34°, 0°, 0°), (86°, 0°, 0°) to (94°, 0°, 0°), (146°, 0°, 0°) to (154°, 0°, 0°), (-6°, 0°, 90°) to (6°, 0°, 90°), (54°, 0°, 90°) to (66°, 0°, 90°), (114°, 0°, 90°) to (126°, 0°, 90°), (-7°, 90°, 90°) to (7°, 90°, 90°), (53°, 90°, 90°) to (67°, 90°, 90°), and (113°, 90°, 90°) to (127°, 90°, 90°).

When $LiNbO_3$ substrates in the above Euler angle ranges are used, a boundary acoustic wave device using a Stoneley wave can

also be provided which has a small spurious response or which will generate no spurious.

Under all the conditions of the calculation results shown in Figs. 10 to 69, propagation losses U3-αm and U3-αf of the Stoneley wave were zero, and hence superior propagation properties can be obtained.

In addition, the acoustic velocity U3-Vm of the Stoneley wave concentrates at approximately 3,000 to 3,400 m/sec, and hence it is understood that the change caused by the cut angle is small.

Accordingly, even when the cut angle is changed, it is understood that an electrode thickness H at a propagation loss of zero can be obtained by equation (4) which will be described later.

In addition, the temperature coefficient of frequency U3-TCFm of the Stoneley wave concentrates at -30 to -40 ppm/°C, and hence it is understood that the change caused by the cut angle is not significant. Accordingly, even when the cut angle is changed, an electrode thickness H at which the temperature coefficient of frequency TCF is decreased can be determined by the equation (4).

[Example 3]

A 120° rotated Y plate X-propagation $LiNbO_3$ substrate, that is, having Euler angles (0°, 30°, 0°) was prepared as the piezoelectric substance 2 using the calculation method described in Example 2, and in consideration of easy thin film formation and a function of counteracting the TCF of $LiNbO_3$, a SiO_2 film

was selected as the dielectric substance 3. By forming electrodes using electrode materials having various densities, boundary acoustic wave devices were formed. Subsequently, the relationships of the electrode thickness of each of the boundary acoustic wave devices thus formed with the acoustic velocity, the propagation loss α (dB/λ), the electromechanical coefficient k^2 (%), and the temperature coefficient of frequency TCF of the Stoneley wave were obtained. The results are shown in Figs. 70 to 116. By the way, the power flow angle PFA was zero under all the conditions.

In the 120° rotated Y plate X-propagation $LiNbO_3$ substrate, the acoustic velocity of a longitudinal wave, that of a slow transverse wave, and that of a slow transverse wave are 6,547, 4,752, and 4,031 m/sec, respectively. In addition, the acoustic velocities of a longitudinal wave and a slow transverse wave of SiO_2 are 5,960 and 3,757 m/sec, respectively. According to Figs. 70 to 116, at an electrode thickness at which the acoustic velocity of the Stoneley wave is lower than 3,757 m/sec, which is the lowest acoustic velocity mentioned above, it is understood that the propagation loss α of the Stoneley wave is zero. That is, by merely using an electrode material having a large density, the propagation loss α of the Stoneley wave cannot be decreased to zero, and it is understood that when the electrode thickness is increased so that the velocity of the Stoneley wave is decreased to less than 3,757 m/sec, the propagation loss α can be decreased to zero.

Hence, in the present invention, the electrode thickness is preferably set so that the acoustic velocity of the Stoneley wave is decreased lower than the lowest acoustic velocity of those mentioned above, and hence the propagation loss α of the Stoneley wave can be decreased to zero.

Furthermore, in the present invention, by using an electrode made of a material having a large density, the acoustic velocity of a transverse wave in the electrode is decreased, and as a result, the energy of the Stoneley wave is concentrated on the electrode. Hence, electric energy applied to the electrode and electric energy of the Stoneley wave are efficiently coupled to each other, and as a result, a large electromechanical coefficient k^2 can be obtained. In addition, since the energy is concentrated on the electrode, the reflection coefficient of the Stoneley wave reflected by electrode fingers forming the electrode is also increased. When the reflection coefficient of the Stoneley wave by the electrode fingers is increased, the number of electrode fingers forming a grating reflector can be decreased. As a result, the size of the boundary acoustic wave device can be reduced. Furthermore, the reflection band of the reflector can also be increased.

When the reflection of electrode fingers forming the IDT 4 is not present, the frequency characteristics of the conductance of the IDT 4 are represented by the symmetric sinc function. On the other hand, when the reflection of the electrode fingers is present, the frequency characteristics of the conductance become

asymmetric, and the conductance at a low frequency side of the band or at a high frequency side thereof becomes large. As the reflection of the electrode fingers is increased, the asymmetry of the above frequency characteristics is enhanced.

By using an IDT having internal reflection as described above, for example, when an input side IDT and an output IDT are disposed in the propagation direction of a boundary acoustic wave, and when reflectors are disposed at two side of the region in which the above IDTs are provided so as to form a longitudinally coupled filter, a filter pass band is formed which reflects the asymmetry of the conductance characteristics. In this case, as the reflection coefficient of the electrode fingers is increased, a steep band region can be designed. As described above, when the reflection coefficient of the finger electrodes forming the IDT can be increased, steeper filter characteristics can be easily obtained.

Fig. 117 is a graph showing the relationship between the density ρ of the electrode material and the electrode thickness H at which the propagation loss of the Stoneley wave is zero. In addition, in the following Table 3, the densities of various metals used as the electrode materials are shown.

[Table 3]

Material	Density (kg/m³)
Al	2699
Ti	4540
Fe	7830
Ni	8845
Cu	8930
Mo	10219
Ag	10500
Ta	16600
Au	19300
W	19300
Pt	21400

As apparent from Fig. 117, when the thickness and the electrode material are determined so as to satisfy the following equation (4), the propagation loss of the Stoneley wave can be decreased to zero.

$H[\lambda]>1/\{1/(3\times19^{7}\times\rho^{-2.22}+0.017)-0.4\}$ · · · · Equation (4)

In addition, when this type of boundary acoustic wave device is manufactured, electrodes such as an IDT are formed on a piezoelectric substrate such as a $LiNbO_3$ substrate by a photolithographic technique including lift-off or dry etching, and on the electrodes, a dielectric film made of SiO_2 or the like is formed by a thin-film forming method including sputtering, evaporation, or CVD. Hence, irregularities are generated on the upper surface of the dielectric film due to the thickness of the IDT. In addition, the dielectric film may be obliquely grown or the film quality may become non-uniform in some cases. When the irregularities, the film growth in an oblique direction, or the non-uniformity of the film quality occurs, the properties of the boundary acoustic wave device are degraded.

In order to avoid the degradation of the properties described above, the thickness of the electrode is preferably small. According to research carried out by the inventors of the present invention, when the thickness H of the electrode is 0.1 λ or more, it becomes difficult to form a dielectric thin film having superior quality. In particular, when the electrode thickness becomes 0.25 λ or more, the aspect ratio of the electrode becomes 1 or more, and it also becomes difficult to form the electrode by using an inexpensive dry etching step or lift-off step. Furthermore, a method and an apparatus used for dielectric thin-film formation are limited, and as a result, it becomes difficult to form a dielectric thin film by general RF magnetron sputtering. Hence, the electrode thickness is preferably 0.25 λ or less and is more preferably 0.1 λ or less.

As apparent from Fig. 117, when an electrode material having a density ρ of 4,711 kg/m^3 or more is used, the electrode thickness H at which the propagation loss of the Stoneley wave becomes zero can be decreased to 0.25 λ or less, and an electrode material having a density ρ of 7,316 kg/m^3 or more is used, the electrode thickness H at which the propagation loss of the Stoneley wave becomes zero can be decreased to 0.10 λ or less. Hence, in the present invention, the density ρ of the electrode material is preferably 4,711 kg/m^3 or more and is more preferably 7,316 kg/m^3 or more.

In addition, as apparent from Figs. 72, 76, 80, 84, 88, 92, 96, 103, 107, 111, and 115, also at the electrode thickness H at

which the condition shown by the above equation (4) is satisfied, the electromechanical coefficient k^2 is sufficiently large, such as 3% to 9.4%. Hence, also at the electrode thickness H at which the above equation (4) holds, a boundary acoustic wave device having a sufficient band width can be provided.

In addition, as apparent from Figs. 73, 77, 81, 85, 89, 93, 97, 100, 104, 108, 112 and 116, it is understood that at the electrode thickness H at which the above equation (4) holds, the absolute values of TCFs of Ag, Au, Cu, Fe, Ta, W, Ti, and Pt become 40 ppm or less. Hence, as the electrode material, at least one selected from the group consisting of Ag, Au, Cu, Fe, Ta, W, Ti, and Pt is preferably used since the temperature coefficient of frequency characteristics can be improved.

[Example 4]

Next, electrodes of Au having a thickness of 0.06 λ were formed on respective $LiNbO_3$ substrates with Euler angles (ϕ, 30°, 0°) and Euler angles (0°, 30°, ψ), and SiO_2 films were formed over the respective electrodes. The relationships of the Euler angles θ and ψ with the acoustic velocities V, the electromechanical coefficients k^2, the propagation losses α, the temperature coefficients of frequency TCF, and the power flow angles (PFA) of the SH type boundary acoustic wave and the Stoneley wave were measured. The results are shown in Figs. 118 to 122 and Figs. 119 to 127. In Figs. 118 to 122, U2 shows the results of the SH boundary acoustic wave, and U3 show the results of the Stoneley wave. In the entire ranges of Euler angles (0°

to 90°, 30°, 0°) and (0°, 30°, 0° to 90°), the propagation loss α was 0 dB/λ.

As apparent from Figs. 118 to 122, the electromechanical coefficient k^2 of the SH boundary acoustic wave is small, such as 0.3% or less, in the range of ϕ of 0° to 15°, and the electromechanical coefficient k^2 of the SH boundary acoustic wave becomes approximately 0% at ϕ of 0°; hence it is understood that the spurious response caused by the SH boundary acoustic wave becomes very small. In addition, in the range of ϕ of 0° to 90°, TCF is superior, such as in the range of -37 to -33 ppm/°C, and the electromechanical coefficient k^2 of the Stoneley wave is sufficiently large, such as 3.5% to 5%; hence, it is understood that a boundary acoustic wave filter can be provided which is preferably used as an RF filter in the narrow to the medium bands. In addition, in the range of ϕ of 0° to 90°, the power flow angel PFA of the Stoneley wave was small, such as ±1.5° or less.

As apparent from Figs. 123 to 127, the electromechanical coefficient k^2 of the SH boundary acoustic wave is small, such as 0.3% or less, in the range of ψ of 0° to 14°, and the electromechanical coefficient k^2 of the SH boundary acoustic wave becomes approximately 0% at ψ of 0°; hence it is understood that the spurious response caused by the SH boundary acoustic wave becomes very small. In addition, in the range of ψ of 0° to 90°, TCF is superior, such as in the range of -36 to -33 ppm/°C. In addition, in the range of ψ of 0° to 45°, the electromechanical coefficient k^2 of the Stoneley wave is sufficiently large, such

as 3.5% to 5%, and hence it is understood that a boundary acoustic wave filter can be provided which is preferably used as an RF filter in the narrow to the medium bands. In addition, in the range of ψ of 0° to 90°, the power flow angel of the Stoneley wave was small, such as ±1.7° or less.

In the present invention, the thicknesses of the dielectric substance and the piezoelectric substance are not necessarily infinite as that of the model which was used for the calculation and may be enough when energy of a boundary acoustic wave is confined to near the electrodes provided at the boundary, that is, for example, a thickness of 1 λ or more may be enough.

In addition, according to the present invention, the piezoelectric substance described above may be a piezoelectric film formed on a dielectric substance.

Furthermore, in the boundary acoustic wave device according to the present invention, in order to increase the strength or to prevent entry of corrosive gases, a protective layer may be formed outside of the boundary acoustic wave device in the lamination direction of the dielectric substance-electrodes-piezoelectric substance laminate structure. In this case, the boundary acoustic wave device of the present invention may be sealed with a packaging material in some cases.

In addition, the protective layer described above may be formed from an insulating material such as titanium oxide, aluminum nitride, or aluminum oxide, a metal film such as Au, Al, or W, or a resin such as a urethane, epoxy, or silicone resin.

Besides Au, Ag, Cu, and Al, the electrodes may be formed from a conductive film made of a metal, such as Fe, Ni, W, Ta, Pt, Mo, Cr, Ti, ZnO, or ITO. In addition, in order to enhance the adhesion and electric power resistance, on an electrode layer formed from Au, Ag, Cu, Al, or an alloy thereof, a second electrode layer formed from another metal material such as Ti, Cr, or a NiCr alloy may be laminated. In this case, the second electrode layer may be provided between the first electrode layer and the piezoelectric substance, between the first electrode layer and dielectric substance, or at both locations mentioned above.

Furthermore, in the present invention, the electrode may include a sheet-shaped electrode film which forms a waveguide or a bus bar, an IDT or comb-shaped electrode exciting a boundary acoustic wave, or a reflector reflecting a boundary acoustic wave.

In addition, in the specification of the present invention, as the Euler angles (ϕ, θ, ψ) representing the cut surface of a substrate and the propagation direction of a boundary acoustic wave, the right-hand Euler angle system is used which has been disclosed in "Acoustic Wave Device Technology Handbook" (edited by Acoustic Wave Device Technology 150th Committee of the Japan Society for the Promotion of Science, first print/first edition issued on Nov. 30, 2001, p. 549). That is, with respect to crystal axes X, Y, and Z of LN, an Xa axis is obtained by ϕ rotation of the X axis about the Z axis in an anticlockwise direction. Next, a Z' axis is obtained by θ rotation of the Z

axis about the Xa axis in an anticlockwise direction. A plane including the Xa axis and having the Z' axis as the normal line is set as the cut surface of a substrate. In addition, the direction of an X' axis obtained by ψ rotation of the Xa axis about the Z' axis in an anticlockwise direction is set as the propagation direction of a boundary acoustic wave.

In addition, as for the crystal axes X, Y, and Z of $LiNbO_3$ represented as the initial values of Euler angles, the Z axis is set parallel to the c-axis, the X axis is set parallel to any one of the three equivalent a-axes in three different directions, and the Y axis is set parallel to the normal line of a plane including the X axis and the Z axis.

In addition, Euler angles equivalent to the Euler angles (ϕ, θ, ψ) of $LiNbO_3$ of the present invention in terms of crystallography may be used. For example, according to "Journal of the Acoustical Society of Japan, Vol. 36, No. 3, 1980, pp. 140 to 145", since $LiNbO_3$ is a crystal belonging to the trigonal 3 m point group, the following equation (A) is satisfied.

$$
\begin{aligned}
F(\phi, \theta, \psi) &= F(60^\circ-\phi, -\theta, \psi) \\
&= F(60^\circ+\phi, -\theta, 180^\circ-\psi) \\
&= F(\phi, 180^\circ+\theta, 180^\circ-\psi) \\
&= F(\phi, \theta, 180^\circ+\psi) \quad \cdots \text{ Equation (A)}
\end{aligned}
$$

In the above equation, F is an optional boundary acoustic-wave property such as the electromechanical coefficient k^2, propagation loss, TCF, PFA, or a natural unidirectional property. As for PFA and natural unidirectional property, for example, when

the propagation direction is reversed, although a plus or a minus sign indicating the direction is changed, the absolute value of the property is not changed, and hence it can be construed that they are practically equivalent to each other. In addition, although the above document relates to the surface acoustic wave, even when the boundary acoustic wave is discussed, the symmetry of crystal may also be handled in the same manner as disclosed in the above document. For example, propagation properties of a boundary acoustic wave at Euler angles (30°, θ, ψ) are equivalent to those at Euler angles (90°, 180°-θ, 180°-ψ). In addition, for example, propagation properties of a boundary acoustic wave at Euler angles (30°, 90°, 45°) are equivalent to those at Euler angles shown in Table 4 below.

In addition, the material constant of the electrode used for calculation in the present invention is the value of a polycrystalline substance; however, even in a crystal substance such as an epitaxial film, since the crystal orientation dependence of a substrate dominantly influences the boundary acoustic wave properties as compared to that of the film itself, also in the case of the equivalent Euler angles represented by the equation (A), equivalent boundary acoustic wave propagation properties which may not cause any practical problems can be obtained.

[Table 4]

ϕ (°)	θ (°)	ψ (°)
30	90	225
30	270	135
30	270	315
90	90	135
90	90	315
90	270	45
90	270	225
150	90	45
150	90	225
150	270	135
150	270	315
210	90	135
210	90	315
210	270	45
210	270	225
270	90	45
270	90	225
270	270	135
270	270	315
330	90	135
330	90	315
330	270	45
330	270	225